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ABERTHAW TESTS
OF
CONCRETE
IN SEA WATER

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SERIES OF 1920

Being the further report of an investigation made by the Aberthaw Construction Company of Boston to determine the effects, both mechanical and chemical, of the action of sea water and varying temperatures upon concrete piers of different composition.

ABERTHAW
CONSTRUCTION COMPANY

BOSTON
ATLANTA
BUFFALO
PHILADELPHIA

TA440
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ABERTHAW TESTS OF CONCRETE IN SEA WATER

SOME years ago it seemed desirable that this Company determine definitely, if possible, whether or not concrete could be so made as to resist all effects of sea water and frost in a northern climate. Permission was obtained from the United States Navy Department to make and store some 16-foot concrete specimens in the Navy Yard at Charlestown, Mass. In the preparation of these specimens, Mr. Herbert L. Sherman of Boston, a cement chemist of established reputation, co-operated with Aberthaw so far as chemical analysis and quantitative tests were concerned.

In January of 1909, twenty-four specimen piers were manufactured and hung under the cap log of a wharf at the Navy Yard. The length of these piles was such that the bottom would always be immersed, even at dead low water, while the top would always remain above high water. The fact that the tide ebbs and flows every twelve hours would thus bring it about that in cold weather the specimens would be alternately frozen and thawed. Some of the specimens were mixed so lean in cement that they were necessarily somewhat porous. It was to be expected that any porous masonry subjected to the treatment planned would show spalling.

The selection of the material and the method of working it was determined in a discussion carried on in the *Engineering News* and by correspondence with those most experienced in masonry work along the water-front.

The first three specimens were composed of one part cement, one of sand, and two of stone; mixed dry, plastic, and very wet, respectively. The next three were made of approximately one part of cement, two of sand, and four of stone, but so proportioned, after mechanical analysis of materials,

that the excess of cement over voids of sand should be 10 per cent, and the excess of mortar over voids of stone should be 10 per cent. These three were likewise mixed dry, plastic and very wet, respectively. The next three were made of one part cement, three of sand, six of stone, and mixed dry, plastic and very wet, respectively.

Next, ten specimens were made in pairs, one of each pair being mixed 1:1:2 and the other 1:3:6. All of these were mixed wet. Two were made from a Portland cement practically free from iron; two of a commercial Portland cement high in alumina; two of a commercial cement low in alumina; two of an iron ore cement practically free from alumina; two of slag cement.

This view shows nine of the piers at almost low tide. The original method of support, by means of the loops in the reinforcing rods, will be noted. As these were gradually weakened by rust, rings were grouted into the cored holes in 1912, as shown in the individual views on pages 9 to 31

The other five samples consisted of one part cement, three of sand and six of stone, and were mixed quite wet. Number 20 was especially well mixed—much more time being taken than is usual in mixing. Number 21 was lost in handling in 1912, while Number 19 disappeared sometime between 1916 and 1920. Number 22 had one-tenth part by weight of hydrated lime substituted for an equivalent amount of the cement, thus making the mixture really 0.1 hydrated lime; 0.9 standard Portland cement; three parts sand; six, stone. Number 23 was mixed with a Sylvester solution of soap and alum; Number 24 contained finely pulverized clay to the amount of 5 per cent of the weight of

the cement. As for brands of cement, the first nine specimens, which were made from the average standard Portland cement, were formed by mixing together equal parts of Vulcanite, Alpha and Giant brands. These were thoroughly mixed in the mortar box and then repacked by weight. The cement of the other specimens was as follows: The cement free from iron was Blanc Stainless; the commercial Portland high in alumina was Atlas; the commercial Portland cement low in alumina was a mixture of equal parts Lehigh and Helderberg; the iron ore cement practically free from alumina was Hermmoor Erz German Portland cement; and the cement made from slag was Universal.

General view of the operations in preparing the piers, showing in foreground the method of weighing water and measuring sand

The stone used was broken trap rock from quarries at Malden, Mass., a cubic foot weighing 90.24 pounds, while the voids were found to be 50 per cent. The stone passed a 1¼-inch ring with the dust screened out. The sand used was clean and sharp, and perhaps a little finer than usual. It was obtained from banks at South Acton, Mass., and when weighed dry averaged 97.18 pounds per cubic foot, while the voids were calculated in the dry sand as 34.2 per cent. As used in the work, the sand contained 4.6 per cent of moisture.

The specimens were made on the first floor of one of the buildings at the Navy Yard, and while the temperature of the room was kept above freezing

point, it was not very warm. The mixer was set on the floor, the feeding chute removed, and the materials were shoveled directly from the floor to the mouth of the mixer, located about 3 feet higher. The mixed materials were then dumped into a water-tight mortar box from which they were shoveled into wheelbarrows and carried a short distance to forms constructed of plank. It should be noted that the specimens were cast in a horizontal position. In order to give them stiffness so that they could be handled without breaking, a ⅝-inch twisted square steel bar was embedded in them for their full length and projected from the upper end, forming a loop. In the upper end of each specimen for a depth of 8 feet there was also placed a steel pipe 2½ inches in outside diameter. This was used simply to core a hole, and was removed, after the specimens were set, in the following manner: Before placing, it was covered on the outside with paraffin, and when the concrete had set, live steam was turned into the pipe, which was then easily and quickly removed. At the extreme top of each specimen was embedded a 3-inch pipe, which was threaded and capped. The object in coring this hole was to ascertain whether water percolated into the specimens from the sea.

Showing reinforcement, and method of supporting pipe for cored hole. The twisted square, running the full length of pier in two opposite corners, was used for some time as a means of support for the pier. See view and caption on page 4

The sand and stone were measured in accurately made frames and were then completely fed into the mixer first; next the cement was shoveled in,

the process requiring about one minute; and after half a minute the water was added with pails, being accurately weighed out, this occupying about one minute. In every case, in as near two minutes as possible after the first water was added, the batch was dumped from the mixer. It required from 15 to 18 minutes entirely to place a batch in the forms, where it was thoroughly spaded and tamped. The workmanship was intended to reproduce as nearly as possible the conditions of actual practice.

The specimens remained in the building for about five weeks before being hung from the cap log, as shown in the photograph.

Leveling off the face of a pier after pouring

In 1909 the core holes left by the withdrawal of the 2½-inch steel pipe were sounded for water. All were dry except seven, which contained water as follows:

No. 1	38 inches
No. 2	65 inches
No. 4	60 inches
No. 5	52 inches
No. 7	16 inches
No. 8	22 inches
No. 15	27 inches

From time to time examinations have been made of the entire set of specimens, and photographs have been taken showing about as much detail as the picture appearing on page 4 of this pamphlet. These photographs are on file at the office of the Aberthaw Construction Company, Boston. Reports on the condition of the specimens appeared in the *Engineering Record*, August 19, 1911, and in the *Engineering News*, November 20, 1913. In December of 1913 and again in June, 1920, each specimen was lifted to the

wharf and carefully photographed. The pictures shown in this pamphlet are half-tones made without retouching from these photographs.

When the specimens were lifted in 1920, it was found that they were covered with crude oil for nearly two-thirds of their length. The oil, mixed with debris, had formed a coating nearly ¼ inch thick at the top of the specimens and extended to within 5 or 6 feet of the bottom, at which point the oil formed only a very thin covering.

To economize in space, the forms for the later piers were placed on top of some of the earlier specimens. The piers in the foreground show both the loop of the reinforcing bar, by which they were long supported, and the end of the pipe making the sounding hole.

The bottom part of all specimens examined in 1920 was thickly covered with mussels and other sea growth. No barnacles were found at this time and the assumption is that they have been destroyed since 1916 by the crude oil floating on the water. To just what extent the oil with which the specimens were coated has interfered with the value of the tests is difficult to say, but it would appear that very little harm will come to the parts of the specimens covered with oil, unless it arises from the action of the oil itself.

While, at this time, it seems hardly advisable to offer an opinion as to the comparative quality of the various specimens, or even to imply that these test piers have, as yet, definitely proved any action or non-action of sea water, it seems reasonable to call attention to the fact that specimens Numbers 2, 3, 14, 16 and 18 show little or no effect from their twelve years' immersion.

Sample No. 1
1913

Sample No. 1

Proportions

1 Cement
1 Sand
2 Stone
248 lb. Water

Cast dry, January 9, 1909. Forms were removed January 11, 1909. Specimen immersed February 27, 1909.

When cast water glistened but did not spatter. Concrete did not quake.

Length	16 ft. 1 in.
Average sectional area	1.69 sq. ft.
Volume	27.04 cu. ft.
Net Volume of Concrete	26.676 "
Gross Weight	4110 lb.
Net Weight of Concrete	4057.5 "
Do. per cu. ft.	152.1 "

Condition March 3, 1910

Front face showed some slight surface erosion, extreme at about half-tide.

Condition December 17, 1913

Face eroded badly for full length. Sides and back probably as good as when poured.

Condition June 9, 1920

Face eroded, but seemingly no worse than in 1913. Corners slightly rounded. A bad crack could be seen on one side and a large chunk was out of a back corner. As specimen was laid on the dock preparatory to replacing in its position under the piers, it shattered badly at about mid-length. This shattering was not due to any blow, but simply to the weight of one end when it was being laid on the pier. The concrete in the center of the specimen was found badly rotted along cracks which were invisible before the specimen was broken. The chunks broken off, however, seemed to be fairly sound. Many cracks could be seen to have existed for some time, as the concrete was badly discolored along them. In placing, the specimen split down the middle nearly to its top.

Sample No. 1
1920

Sample No. 2
1913

Sample No. 2

Proportions

1 Cement
1 Sand
2 Stone
295 lb. Water

Cast January 8, 1909. Forms were removed January 11, 1909. Specimen immersed March 1, 1909.

When cast no water spattered from surface by tamping, but a little movement could be seen as far as 12 inches away.

Length	16 ft.
Average sectional area	1.788 sq. ft.
Volume	28.61 cu. ft.
Net Volume of Concrete	28.252 "
Gross Weight	4320 lb.
Net Weight of Concrete	4267.5 "
Do. per cu. ft.	151.06 "

Condition March 3, 1910

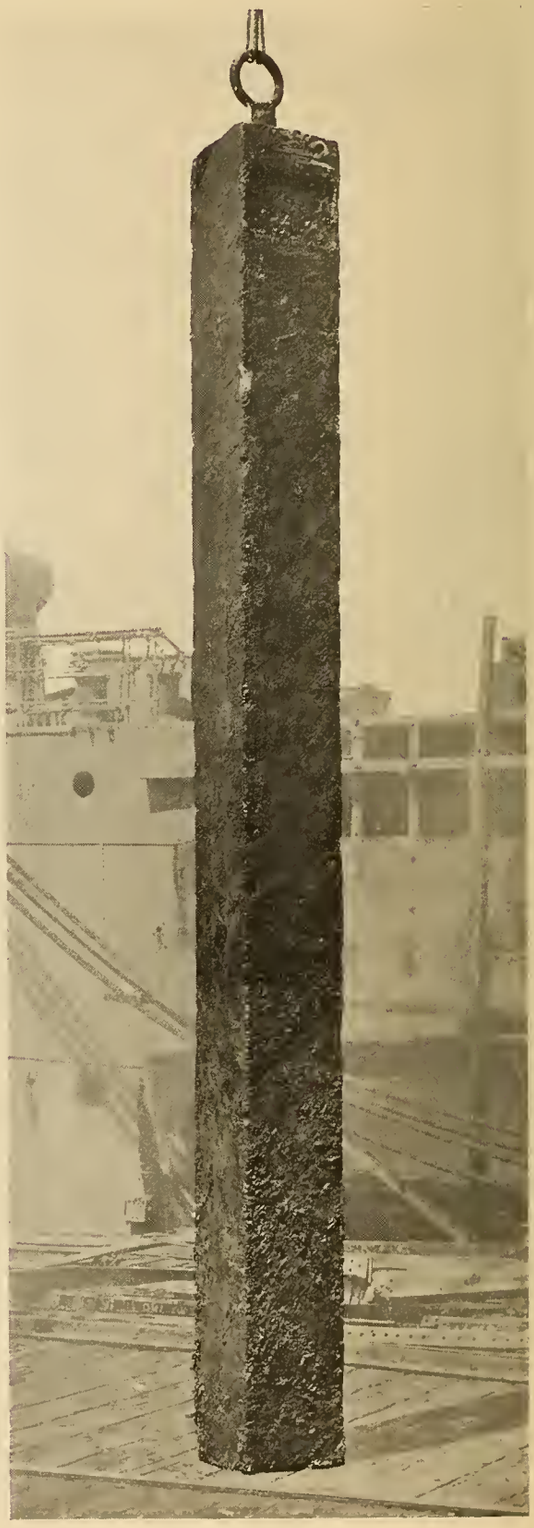
Apparently in as good condition as when placed.

Condition December 17, 1913

Face, sides and back slightly pitted below mid-water. Specimen seems in good condition.

Condition June 9, 1920

Face slightly pitted. Corners slightly pitted, but not badly rounded. Back slightly pitted. Specimen seems in very good condition.



Sample No. 2
1920

Sample No. 3
1913

Sample No. 3

Proportions

1 Cement
1 Sand
2 Stone
425 lb. Water

Cast very wet, January 9, 1909. Forms were removed January 11, 1909. Specimen immersed March 1, 1909.

When cast the concrete was soft enough to run out of an overturned barrow, but it would not flow like syrup.

Length	16 ft. 0½	in.
Average sectional area	1.77	sq. ft.
Volume	28.39	cu. ft.
Net Volume of Concrete	28.044	"
Gross Weight	4250	lb.
Net Weight of Concrete	4197.5	"
Do. per cu. ft.	145.04	"

Condition March 3, 1910

Apparently in as good condition as when placed.

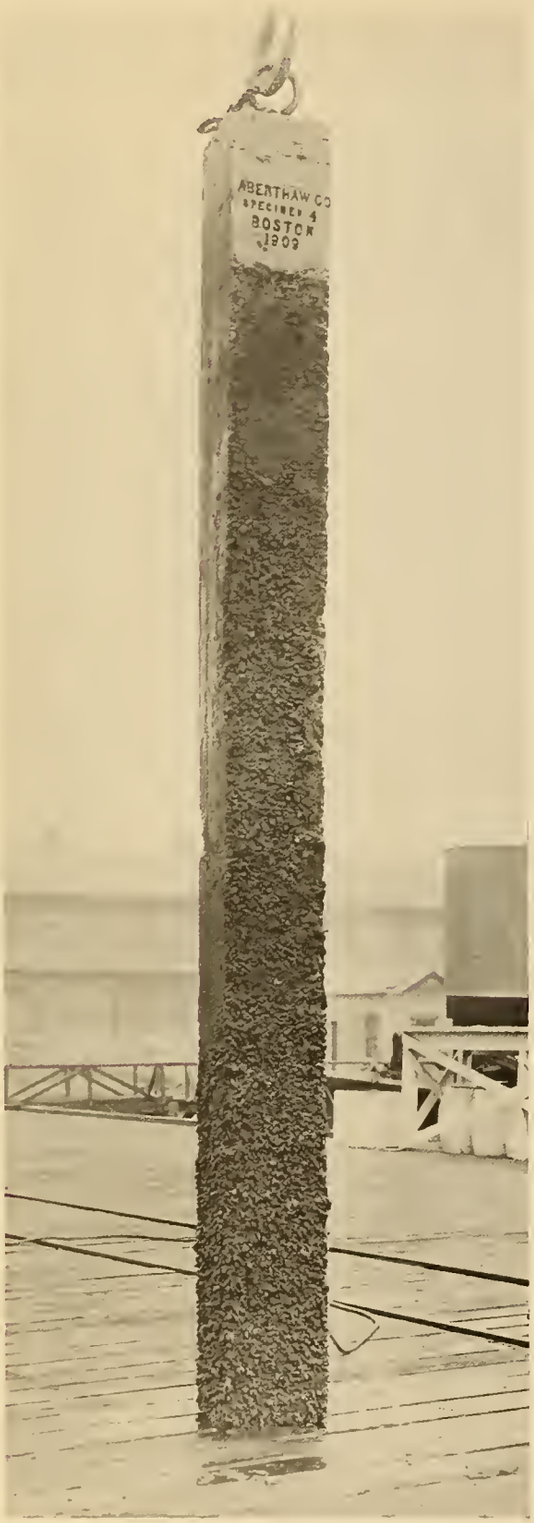
Condition December 17, 1913

Face somewhat pitted. Edges good, sides good, back good, slightly pitted.

Condition June 9, 1920

Appears unchanged since photograph was taken in 1913. In very good condition. Corners sharp. Face only very slightly pitted.

Sample No. 3
1920



Sample No. 4
1913

Sample No. 4

Proportions

1 Cement
2½ Sand
4½ Stone
165 lb. Water

Cast very dry, January 9, 1909. Forms were removed January 11, 1909. Specimen immersed March 1, 1909.

When cast there was no free water, but the surface was moist.

Length	16	ft.
Average sectional area	1.79	sq. ft.
Volume	28.64	cu. ft.
Net Volume of Concrete	28.267	"
Gross Weight	4175	lb.
Net Weight of Concrete	4122.5	"
Do. per cu. ft.	145.82	"

Condition March 3, 1910

Slightly pitted on the sides — more so on front face, where the fine material had apparently been eroded, exposing the stones but leaving them firmly embedded. The extreme erosion was about 1 inch.

Condition December 17, 1913

Face badly eaten from high water to bottom — a little worse between high and low water. Aggregate exposed on entire face. Back good — slightly flaked at mid-water. Sides look as though specimen had been poorly spaded — aggregates exposed in streaks.

A detailed view of the face is shown on page 32.

Condition June 9, 1920

Bottom seems no worse than in 1913. Between high and low water the corners are rounded and pitted. Large pits occurred at the back corners about mid-height. The top half of the specimen was covered with oil.

Sample No. 4
1920

Sample No. 5
1913

Sample No. 5

Proportions

1 Cement
2½ Sand
4½ Stone
195 lb. Water

Cast plastic, January 9, 1909. Forms were removed January 11, 1909. Specimen immersed February 27, 1909.

When cast the top surface was quite wet, just barely spattered and quaked a very little at a few inches from tamp.

Length	15 ft. 11 in.
Average sectional area	1.75 sq. ft.
Volume	27.85 cu. ft.
Net Volume of Concrete	27.46 "
Gross Weight	4180 lb.
Net Weight of Concrete	4127.5 "
Do. per cu. ft.	150.3 "

Condition March 3, 1910

Apparently in as good condition as when placed.

Condition December 17, 1913

Specimen slightly pitted on all sides from high water to bottom.

Condition June 9, 1920

The back at mid-height was badly pitted as if from a blow. Corners slightly gone at mid-height. Specimen seemed in very good condition, apparently as good as in 1913.

Sample No. 5
1920

Sample No. 6
1913

Sample No. 6

Proportions

1 Cement
2½ Sand
4½ Stone
345 lb. Water

Cast very wet, January 9, 1909. Forms were removed January 11, 1909. Specimen immersed February 23, 1909.

Length	15 ft. 11¾	in.
Average sectional area	1.79	sq. ft.
Volume	28.6	cu. ft.
Net Volume of Concrete	28.225	"
Gross Weight	4350	lb.
Net Weight of Concrete	4297.5	"
Do. per cu. ft.	152.2	"

Condition March 3, 1910

The surface appeared to be somewhat soft.

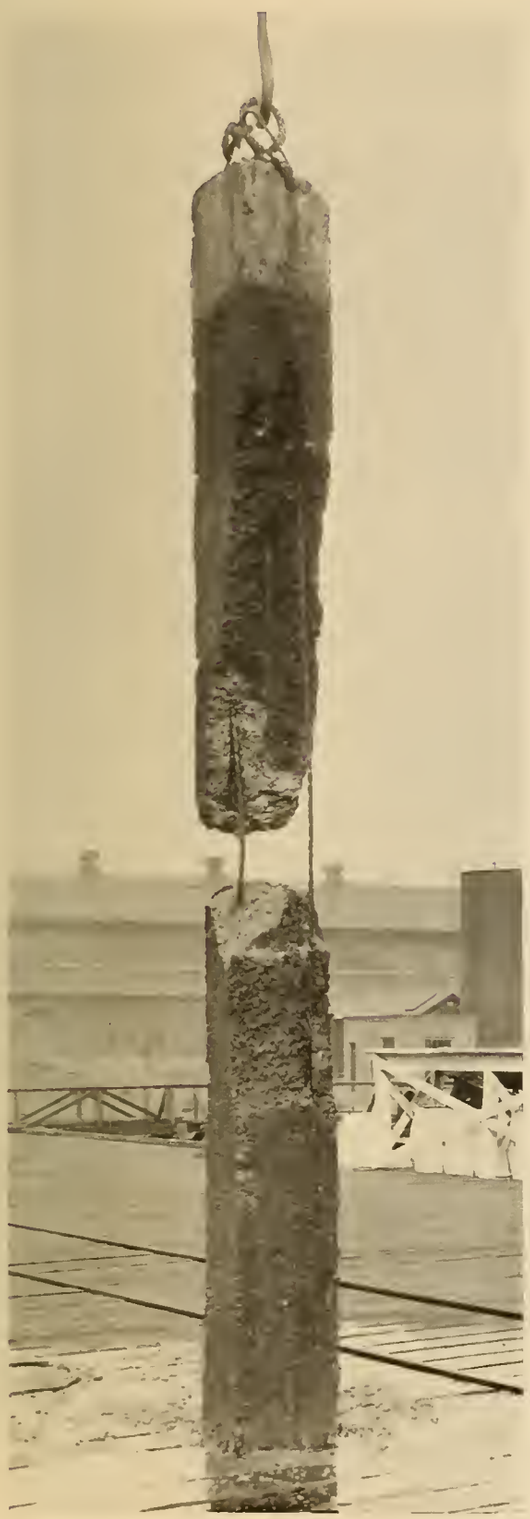
Condition December 17, 1913

All sides are in good condition for full length. Face a little pitted, corners eaten a trifle around low tide.

Condition June 9, 1920

Corners are gone about mid-height. Bottom fairly sound. Front pitted about mid-height. Reinforcement exposed about mid-height. Back pitted between high and low water. The fine aggregate was rotted for about ½ inch in depth at mid-height.

Sample No. 6
1920



Sample No. 7
1913

Sample No. 7

Proportions

1 Cement
3 Sand
6 Stone
182 lb. Water

Cast quite dry, January 11, 1909. Forms were removed January 13, 1909. Specimen immersed February 27, 1909.

When cast did not quake.

Length	16 ft.
Average sectional area	1.82 sq. ft.
Volume	29.12 cu. ft.
Net Volume of Concrete	28.74 "
Gross Weight	4150 lb.
Net Weight of Concrete	4097.5 "
Do. per cu. ft.	142.5 "

Condition March 3, 1910

Slightly pitted on the sides — more so on front face, where the fine material had apparently been eroded, exposing the stones but leaving them firmly embedded.

Condition December 17, 1913

Specimen entirely eaten through at 3½ feet above low water, about a foot in length, all gone. Bars holding together. Back side eaten on a slant for 10 feet. Only slightly eaten below low water line. Material dead at eaten section.

Condition June 9, 1920

Specimen entirely gone between high and low water. Top of bottom part badly disintegrated. In very good condition at the very bottom. Fine aggregate rotted for about ½ inch in depth below high water.

Sample No. 7
1920

Sample No. 8
1913

Sample No. 8

Proportions

1 Cement
3 Sand
6 Stone
240 lb. Water

Cast plastic, January 11, 1909. Forms were removed January 13, 1909. Specimen immersed February 23, 1909.

When cast moderate tamping showed quaking; spots of water on surface.

Length	15 ft. 11 $\frac{9}{16}$	in.
Average sectional area	1.82	sq. ft.
Volume	29.05	cu. ft.
Net Volume of Concrete	28.666	"
Gross Weight	4255	lb.
Net Weight of Concrete	4202.5	"
Do. per cu. ft.	146.58	"

Condition March 3, 1910

Apparently in as good condition as when placed.

Condition December 17, 1913

Front and sides somewhat pitted. Back face eaten badly from low tide to mid-tide for about 2 feet, — eaten to a depth of 5 inches. Streak eaten down center of back side from high tide to bad spot. A detailed view of the back is shown on page 32.

Condition June 9, 1920

Seems in about the same condition as in 1913. Is worse around low water. Back badly gone from about 3 feet from the bottom to 3 feet from the top. Steel exposed in the back face. One bad hole occurs about mid-height almost one-half through the specimen, another at about three-quarters the height, or about at high water. Bottom seems good. Fine aggregate rotted between high and low water.

Sample No. 8
1920

Sample No. 9
1913

Sample No. 9

Proportions

1 Cement
3 Sand
6 Stone
343 lb. Water

Cast wet, January 11, 1909. Forms were removed January 13, 1909. Specimen immersed February 23, 1909.

When cast concrete spattered and quaked. Water ran off.

Length	16 ft. 1¼	in.
Average sectional area	1.8	sq. ft.
Volume	28.99	cu. ft.
Net Volume of Concrete	28.615	"
Gross Weight	4215	lb.
Net Weight of Concrete	4162.5	"
Do. per cu. ft.	145.4	"

Condition March 3, 1910

Apparently in as good condition as when placed.

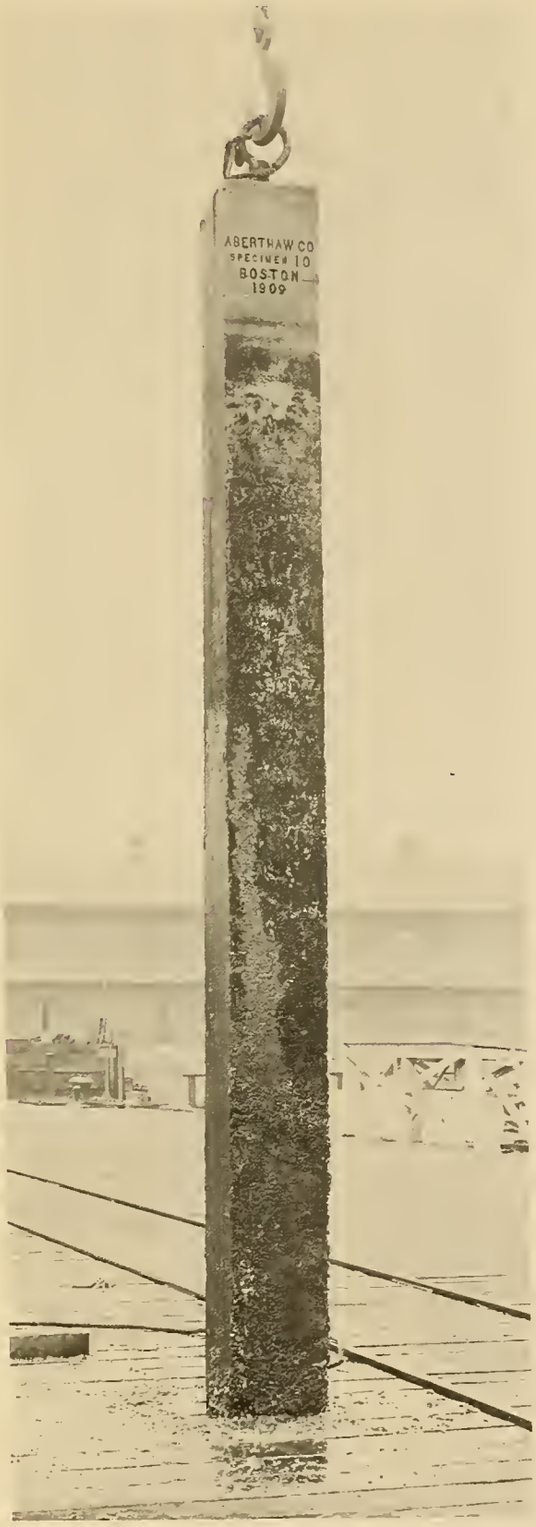
Condition December 17, 1913

General condition good. Face a little pitted. Edges all eaten a little.

Condition June 9, 1920

Front corners badly eaten between high and low water. Concrete fairly solid. Faces only slightly pitted. Back corners pitted.

Sample No. 9
1920



Sample No. 10
1913

Sample No. 10

Proportions

1 Blanc Cement
1 Sand
2 Stone
305 lb. Water

Cast wet, January 12, 1909. Forms were removed January 14, 1909. Specimen immersed February 27, 1909.

When cast concrete quaked when tamped lightly. Cement acted quickly.

Length	15 ft. 11½	in.
Average sectional area	1.8	sq. ft.
Volume	30.4	cu. ft.
Net Volume of Concrete	30.032	"
Gross Weight	4320	lb.
Net Weight of Concrete	4267.5	"
Do. per cu. ft.	142.1	"

Condition March 3, 1910

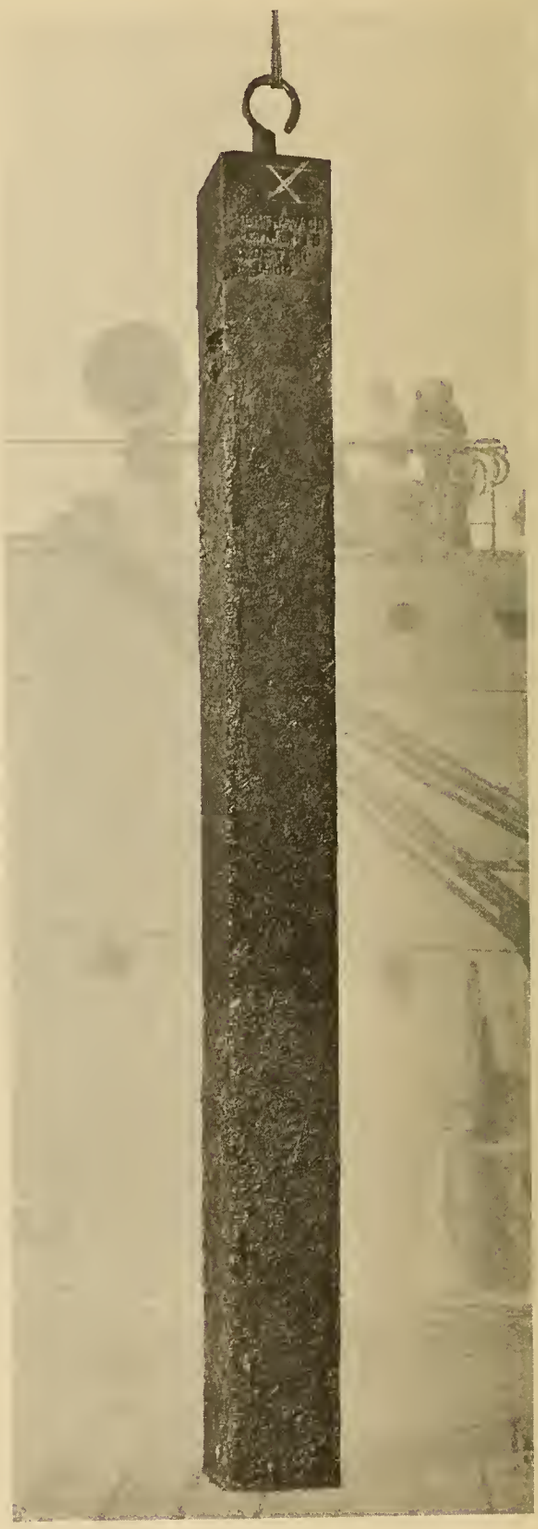
Apparently in as good condition as when placed.

Condition December 17, 1913

Condition good. Bottom and sides hardly touched. Front slightly pitted. Edges fairly sharp.

Condition June 9, 1920

Apparently as good as in 1913. Front slightly pitted. Sides and back hardly touched. Concrete solid.



Sample No. 10
1920

Sample No. 11
1913

Sample No. 11

Proportions

1 Blanc Cement
3 Sand
6 Stone
353 lb. Water

Cast wet, January 12, 1909. Forms were removed January 14, 1909. Specimen immersed February 27, 1909.

When cast flowed off shovel easily and concrete when tamped flowed water off form.

Length	16	ft.
Average sectional area	1.86	sq. ft.
Volume	29.76	cu. ft.
Net Volume of Concrete	29.389	"
Gross Weight	4350	lb.
Net Weight of Concrete	4297.5	"
Do. per cu. ft.	146.2	"

Condition March 3, 1910

Apparently in as good condition as when placed.

Condition December 17, 1913

Condition good. Face pitted slightly from mid-water. Back good. Sides slightly pitted around low tide mark. Edges fairly good.

Condition June 9, 1920

Large hole in front face nearly half way through between high and low tide. Fine aggregate rotted for ½ to 1½ inches depth. Back corners badly pitted. Top good, bottom good. Concrete worse at about high water.

Sample No. 11
1920

Sample No. 12
1913

Sample No. 12

Proportions

1 Atlas Cement
1 Sand
2 Stone
325 lb. Water

Cast wet, January 12, 1909. Forms were removed January 14, 1909. Specimen immersed February 27, 1909.

When cast quaked with light tamping.

Length	16	ft.
Average sectional area	1.81	sq. ft.
Volume	28.96	cu. ft.
Net Volume of Concrete	28.579	"
Gross Weight	4225	lb.
Net Weight of Concrete	4172.5	"
Do. per cu. ft.	145.9	"

Condition March 3, 1910

A very slight action was noticeable on the front face.

Condition December 17, 1913

Very good condition. Edges all sharp at mid-water. A slight flaking in back. Front slightly pitted from mid-water to bottom; a little more above low water.

Condition June 9, 1920

Corners broken slightly. Faces slightly pitted about mid-height. Bottom and top good.

Sample No. 12
1920

Sample No. 13
1913

Sample No. 13

Proportions

1 Atlas Cement
3 Sand
6 Stone
345 lb. Water

Cast wet, January 12, 1909. Forms were removed January 14, 1909. Specimen immersed February 27, 1909.

When cast flowed off shovel easily; slight tamping showed quaking; spattered when tamped hard. Surface glazed.

Length	15 ft. 11 in.	
Average sectional area	1.8	sq. ft.
Volume	28.7	cu. ft.
Net Volume of Concrete	28.34	"
Gross Weight	4100	lb.
Net Weight of Concrete	4047.5	"
Do. per cu. ft.	142.8	"

Condition March 3, 1910

A very slight action was noticeable on the front face.

Condition December 17, 1913

Condition fairly good from top to low water line. One corner at low water eaten in about 1½ inches. Sides good, back good, bottom good. Face eaten, a little rough all the way down. Edges eaten off.

Condition June 9, 1920

Badly eaten between high and low water. Concrete very rotten for a depth of 1 to 2 inches in middle of specimen. Corners could be flaked off in large chunks.

Sample No. 13
1920

Sample No. 14
1913

Sample No. 14

Proportions

1 Helderberg & Lehigh Cement mixed
1 Sand
2 Stone
330 lb. Water

Cast wet, January 13, 1909. Forms were removed January 15, 1909. Specimen immersed February 23, 1909.

When cast quaked with light tamping.

Length	16	ft.
Average sectional area	1.79	sq. ft.
Volume	28.64	cu. ft.
Net Volume of Concrete	28.274	"
Gross Weight	4130	lb.
Net Weight of Concrete	4077.5	"
Do. per cu. ft.	144.2	"

Condition March 3, 1910

Apparently in as good condition as when placed.

Condition December 17, 1913

Condition very good. Corners all sharp for full length. Face only a little pitted. Sides and back hardly touched.

Condition June 9, 1920

In very good condition. Corners only very slightly gone at low tide. Face slightly pitted. Sides and back slightly touched.

Sample No. 14
1920

Sample No. 15
1913

Sample No. 15

Proportions

1 Helderberg & Lehigh Cement mixed
3 Sand
6 Stone
335 lb. Water

Cast wet, January 13, 1909. Forms were removed January 15, 1909. Specimen immersed February 27, 1909.

When cast quaked with light tamping.

Length	15 ft. 11 in.
Average sectional area	1.81 sq. ft.
Volume	28.89 cu. ft.
Net Volume of Concrete	28.52 "
Gross Weight	4125 lb.
Net Weight of Concrete	4072.5 "
Do. per cu. ft.	142.7 "

Condition March 3, 1910

A very slight action was noticeable on the front, and the face appeared softer than it should.

Condition December 17, 1913

Condition good entire length. Edges slightly eaten. Face pitted. Sides and back hardly touched.

Condition June 9, 1920

Pitted at low water on face and sides. Corners rather badly pitted between high and low water. Outer concrete and corners rotted ½ inch in depth. Specimen in fairly good condition.

Sample No. 15
1920

Sample No. 16
1913

Sample No. 16

Proportions

1 Iron Ore Cement
1 Sand
2 Stone
315 lb. Water

Cast wet, January 15, 1909. Forms were removed January 18, 1909. Specimen immersed February 23, 1909.

When leveled off, showed oily streaks in water on top.

Length	15 ft. 11 in.
Average sectional area	1.8 sq. ft.
Volume	28.7 cu. ft.
Net Volume of Concrete	28.32 "
Gross Weight	4290 lb.
Net Weight of Concrete	4237.5 "
Do. per cu. ft.	149.6 "

Condition March 3, 1910

Apparently in as good condition as when placed.

Condition December 17, 1913

Good all over and on all sides. Apparently no eating action has taken place.

Condition June 9, 1920

Good all over. Slightly pitted between high and low water on face and sides. Corners very sharp.

Sample No. 16
1920

Sample No. 17
1913

Sample No. 17

Proportions

1 Iron Ore Cement
3 Sand
6 Stone
293 lb. Water

Cast wet, January 15, 1909. Forms were removed January 18, 1909. Specimen immersed February 27, 1909.

When leveled off, showed oily streaks in water on top.

Length	16	ft.
Average sectional area	1.81	sq. ft.
Volume	28.96	cu. ft.
Net Volume of Concrete	28.589	"
Gross Weight	4225	lb.
Net Weight of Concrete	4172.5	"
Do. per cu. ft.	145.9	"

Condition March 3, 1910

Apparently in as good condition as when placed.

Condition December 17, 1913

All four sides slightly eaten from high tide to bottom. Most of action around low tide mark. Corners eaten. All eating action on mortar. Stone seems unaffected. Deepest holes less than $\frac{1}{4}$ inch.

Condition June 9, 1920

Badly pitted on faces between high and low water, especially around low water. Coarse aggregate exposed. Concrete solid. Deepest pits about 1 inch. Corners badly eaten.

Sample No. 17
1920

Sample No. 18
1913

Sample No. 18

Proportions

1 Universal Cement
1 Sand
2 Stone
330 lb. Water

Cast wet, January 13, 1909. Forms were removed January 15, 1909. Specimen immersed February 27, 1909.

When cast quaked with light tamping.

Length	16 ft. 7/8 in.
Average sectional area	1.8 sq. ft.
Volume	28.93 cu. ft.
Net Volume of Concrete	28.58 "
Gross Weight	4215 lb.
Net Weight of Concrete	4162.5 "
Do. per cu. ft.	145.6 "

Condition March 3, 1910

Apparently in as good condition as when plaeed.

Condition December 17, 1913

Good all over and on all sides. Back slightly pitted.

Condition June 9, 1920

Good on the face and sides. Baek slightly pitted. Corners slightly eaten and rounded between high and low water. Concrete sound.

Sample No. 18
1920

Sample No. 19
1913

Sample No. 19

Proportions

1 Universal Cement
3 Sand
6 Stone
370 lb. Water

Cast wet, January 13, 1909. Forms were removed January 15, 1909. Specimen immersed February 23, 1909.

When cast quaked with light tamping.

Length		16 ft.
Average sectional area	1.8	sq. ft.
Volume	28.8	cu. ft.
Net Volume of Concrete	28.425	"
Gross Weight	4125	lb.
Net Weight of Concrete	4072.5	"
Do. per cu. ft.	143.3	"

Condition March 3, 1910

A slight roughness showed on the front face.

Condition December 17, 1913

Fair above high water line, all sides. Badly eaten between high and low water. Corners all gone, several inches deep in places. Back eaten all over to a depth of up to 4 inches. Steel partly exposed. Concrete soft and crumbly. Fair condition below low water mark.

Condition June 9, 1920

This pile missing.

Note: June 9, 1920

This specimen could not be found.

Sample No. 20
1913

Sample No. 20

Proportions

1 Cement
3 Sand
6 Stone
275 lb. Water

Cast normal, January 14, 1909. Forms were removed January 16, 1909. Specimen immersed February 23, 1909.

When cast quaked with light tamping.

Length	16 ft.
Average sectional area	1.79 sq. ft.
Volume	28.64 cu. ft.
Net Volume of Concrete	28.263 "
Gross Weight	4165 lb.
Net Weight of Concrete	4112.5 "
Do. per cu. ft.	145.5 "

Condition March 3, 1910

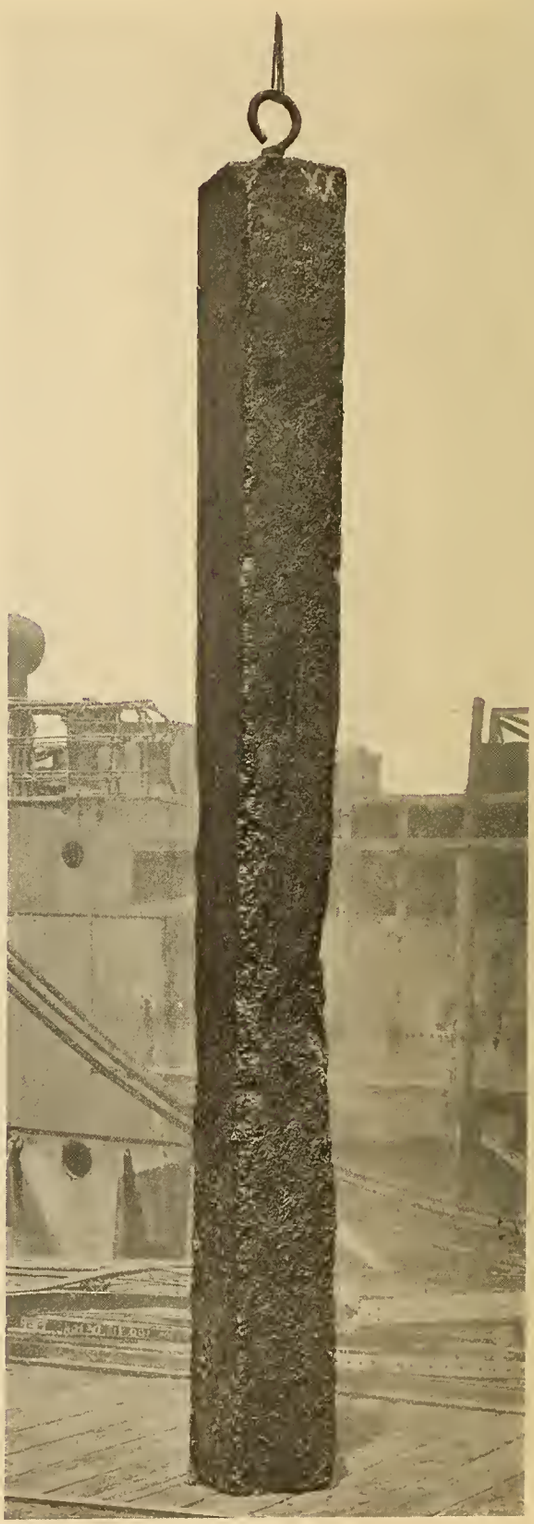
A slight roughness showed on the front face.

Condition December 17, 1913

Very slightly flaked on all four sides between low water and half way to high water. Below water, eaten in a few small spots for $\frac{1}{16}$ inch or so. Corners all slightly eaten.

Condition June 9, 1920

Pitted on all faces from high tide to bottom. Front corners badly gone. Back corners badly pitted, but not gone. Fine aggregate somewhat rotten between high and low water.



Sample No. 20
1920

Sample No. 22
1913

Sample No. 22

Proportions

1 Part (Cement 0.9, Hydrated Lime 0.1)
3 Sand
6 Stone
325 lb. Water

Cast wet, January 16, 1909. Forms were removed January 18, 1909. Specimen immersed February 23, 1909.

The lime was mixed thoroughly with the dry cement. The specimen when cast quaked with light tamping.

Length		16 ft.
Average sectional area	1.8	sq. ft.
Volume	28.8	cu. ft.
Net Volume of Concrete	28.427	"
Gross Weight	4225	lb.
Net Weight of Concrete	4172.5	"
Do. per cu. ft.	146.7	"

Condition March 3, 1910

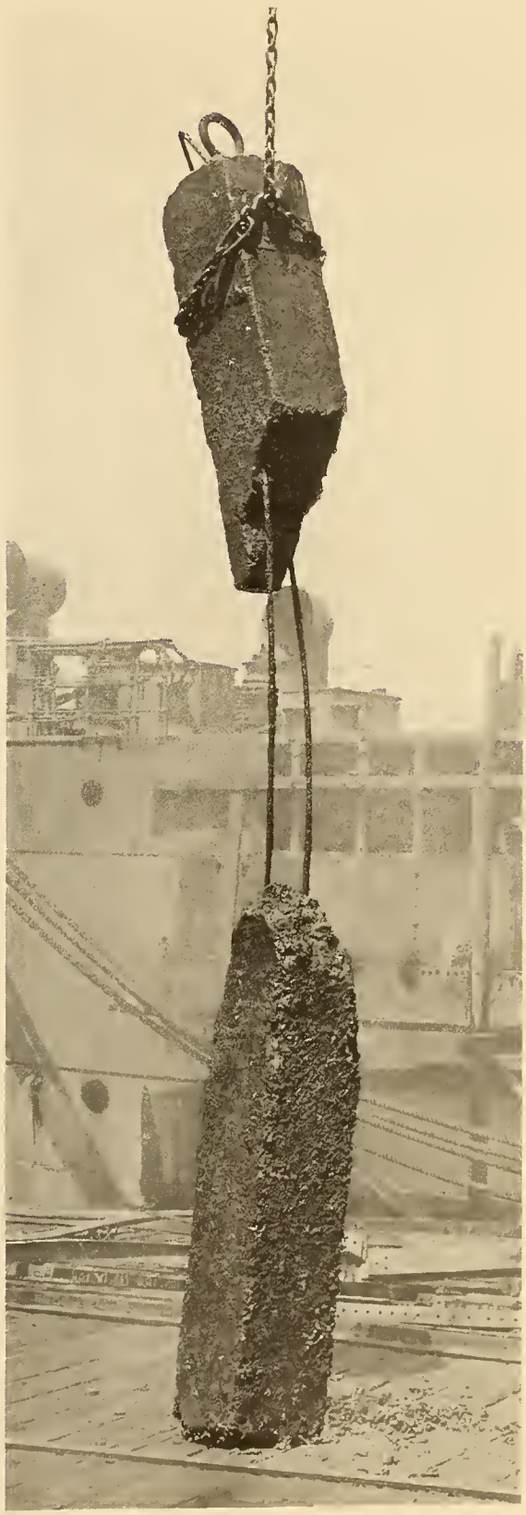
This specimen showed little change. It was, however, cracked when first placed. When examined this crack showed water leaking out.

Condition December 17, 1913

Front face badly pitted from mid-water clear to bottom; not quite so bad on lower 2 feet. At mid-water badly eaten to depth of 4 inches. Material soft and dead at this point. Sides and back equally pitted. Crack in middle of worst eaten part.

Condition June 9, 1920

Entirely gone in middle, about 4 feet at the top and 6 feet at the bottom remaining, but this is badly rotted.



Sample No. 22
1920

Sample No. 23
1913

Sample No. 23

Proportions

1 Cement (with Sylvester solution — soap and alum)
3 Sand
6 Stone
298 lb. Water

Cast wet, January 16, 1909. Forms were removed January 18, 1909. Specimen immersed February 23, 1909.

Mixed the alum thoroughly with the dry cement; dissolved the soap in water. The specimen when cast quaked with light tamping.

Length	16 ft. 1½ in.
Average sectional area	1.82 sq. ft.
Volume	29.34 cu. ft.
Net Volume of Concrete	28.97 "
Gross Weight	4050 lb.
Net Weight of Concrete	3997.5 "
Do. per cu. ft.	137.9 "

Condition March 3, 1910

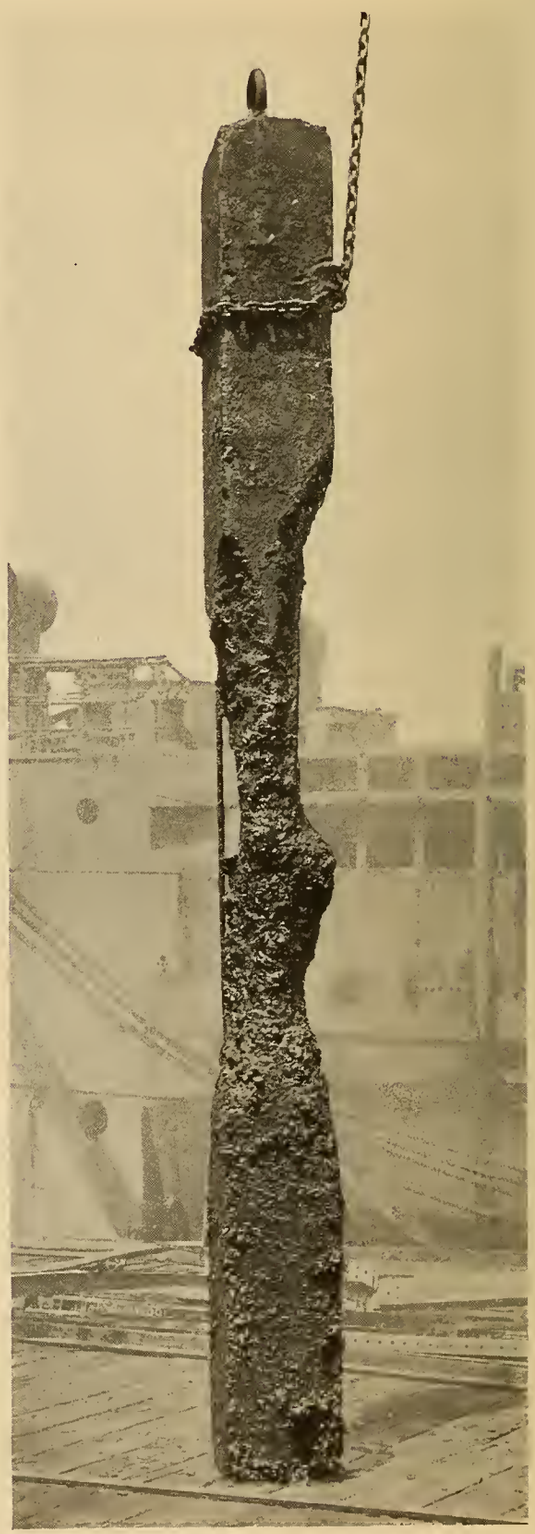
This specimen had a very small crack on its face when placed. When examined it was found to be cracked practically all the way through. The corners were eroded in places, which may have been caused by bumps from a floating obstacle.

Condition December 17, 1913

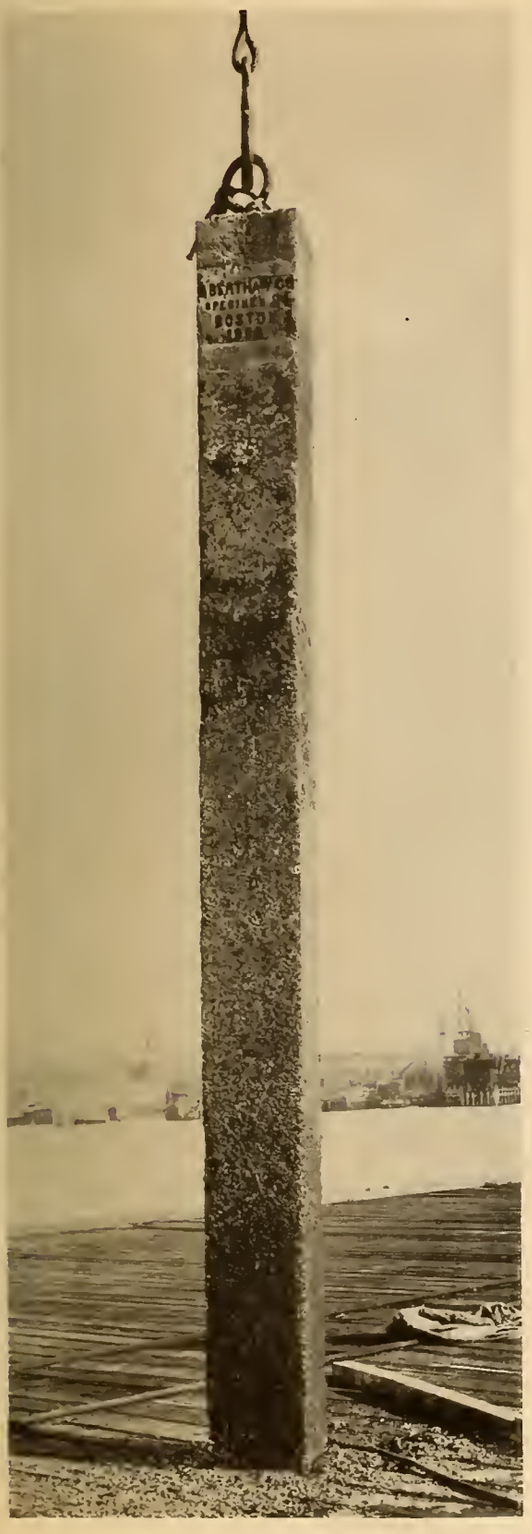
Face badly eaten just above low water mark. All four edges and back badly eaten for 3 feet below low water mark. Corners at bottom gone. All faces slightly pitted. Not much action above mid-water line.

Condition June 9, 1920

Concrete between high and low water badly rotted. Less than one-half of the original area of the specimen remains between high and low water.



Sample No. 23
1920



Sample No. 24
1913

Sample No. 24

Proportions

1 Cement with 5% (or 23½ lb.) Pulverized Clay
3 Sand
6 Stone
275 lb. Water

Cast wet, January 14, 1909. Forms were removed January 16, 1909. Specimen immersed February 23, 1909.

When cast showed quaking and spattered from light tamping.

Length	15 ft. 1¼	in.
Average sectional area	1.81	sq. ft.
Volume	27.34	cu. ft.
Net Volume of Concrete	26.967	"
Gross Weight	4150	lb.
Net Weight of Concrete	4097.5	"
Do. per cu. ft.	151.6	"

Condition March 3, 1910

The outer face was somewhat soft.

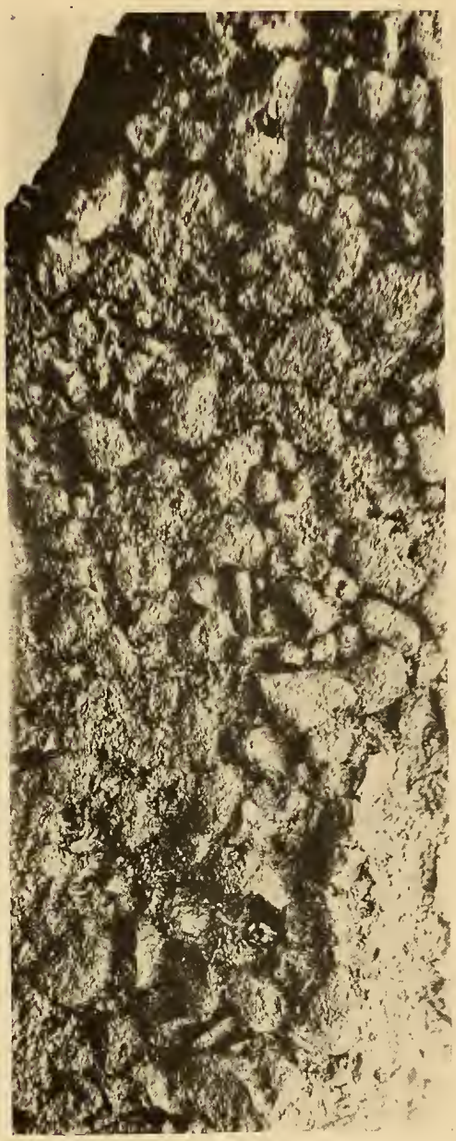
Condition December 17, 1913

Good above water line. Surfaces between high and low tide eaten somewhat. Corners eaten all the way from high water to bottom. Took close photograph of small section showing typical eating. Face little worse than sides.

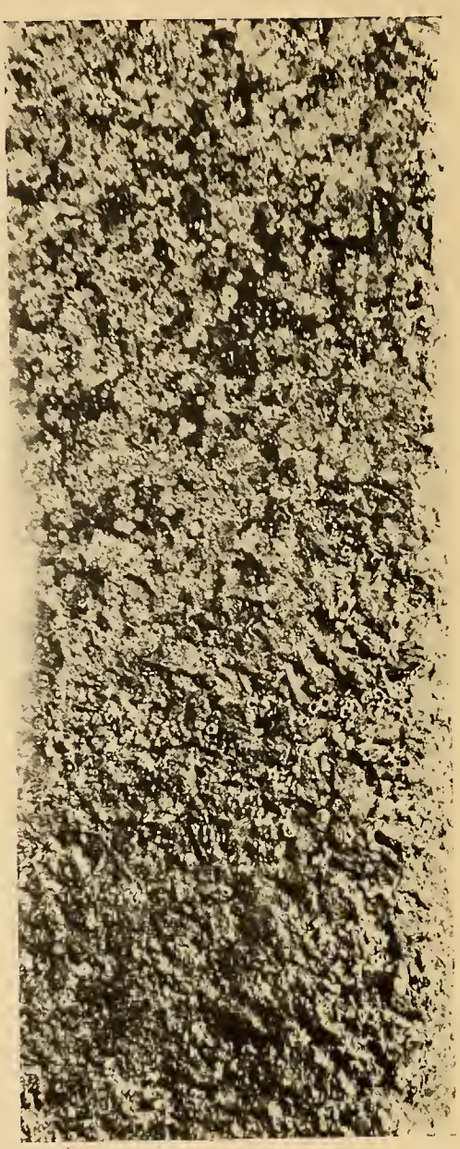
Condition June 9, 1920

Face, sides and back pitted between high and low water, especially just above low water. Back corners badly eaten.

Sample No. 24
1920



Detailed View of an "Average Poor" Specimen (No. 4). The white in the lower right corner shows where the surface was picked off with the finger nail — indicating complete local disintegration



Detailed View of an "Average Good" Specimen, showing the aggregate exposed but well embedded in the cement. This surface, while somewhat rough, is nearly the original surface

Small barnacles appear on both these specimens — particularly that on the right

REPORT OF CEMENT TESTS

NOTHING out of the ordinary was noticed in the tests of the cement used for the piers except for the very long time taken by the iron ore cement in getting a hard set. This is interesting as showing the effect on the set of the almost total absence of alumina. The use of hydrated lime was shown to give a very quick set — although the initial set was very rapid, the paste was easily worked to a soft mix for several hours after getting its initial set.

Test of white Portland cement

Per cent passing No. 100 sieve, 94.4; No. 200 sieve, 75

Initial set — 25 minutes. Final set — 3 hr. 20 min. — 23% water

Tensile strength neat test samples

24 hours average 277 lb. per sq. in. — 23% water
7 days " 549 " " " "
28 days " 726 " " " "

Tensile strength, one part cement to three of sand by weight —

(Ottawa sand) 7 days average 191 lb. per sq. in — 9% water
28 days " 319 " " " "

(Bank sand) 7 days average 159 lb. per sq. in. — 10% water
28 days " 218 " " " "

Test of Portland cement with average alumina content

Per cent passing No. 100 sieve, 94.8; No. 200 sieve, 79.6

Initial set — 1 hr. 35 min. Final set — 4 hr. 45 min. — 22% water

Tensile strength neat test samples — 22% water

24 hours average 313 lb. per sq. in.
7 days " 660 " " " "
28 days " 755 " " " "

Tensile strength, one part cement to three of sand by weight —

(Ottawa sand) 7 days average 264 lb. per sq. in. — 9% water
28 days " 360 " " " "

(Bank sand) 7 days average 217 lb. per sq. in. — 10% water
28 days " 318 " " " "

Test of Portland cement with high alumina content

Per cent passing No. 100 sieve, 94.2; No. 200 sieve, 76.2
Initial set — 1 hr. 45 min. Final set — 4 hr. 10 min. — 22% water
Tensile strength neat test samples

24 hours average 342 lb. per sq. in.
7 days " 677 " " " "
28 days " 744 " " " "

Tensile strength, one part cement to three of sand by weight —
(Ottawa sand) 7 days average 272 lb. per sq. in. — 9% water
28 days " 304 " " " "
(Bank sand) 7 days average 168 lb. per sq. in. — 10% water
28 days " 211 " " " "

Test of Portland cement with low alumina content

Per cent passing No. 100 sieve, 93.8; No. 200 sieve, 78.8
Initial set — 2 hr. 10 min. Final set — 5 hr. — 22% water
Tensile strength neat test samples

24 hours average 312 lb. per sq. in.
7 days " 636 " " " "
28 days " 741 " " " "

Tensile strength, one part cement to three of sand by weight —
(Ottawa sand) 7 days average 184 lb. per sq. in. — 9% water
28 days " 312 " " " "
(Bank sand) 7 days average 133 lb. per sq. in. — 10% water
28 days " 271 " " " "

Test of Portland cement made with slag

Per cent passing No. 100 sieve, 95.6; No. 200 sieve, 78.8
Initial set — 35 min. Final set — 2 hr. — 22% water
Tensile strength neat test samples

24 hours average 315 lb. per sq. in.
7 days " 608 " " " "
28 days " 717 " " " "

Tensile strength, one part cement to three of sand by weight —
(Ottawa sand) 7 days average 194 lb. per sq. in. — 9% water
28 days " 258 " " " "
(Bank sand) 7 days average 166 lb. per sq. in. — 10% water
28 days " 181 " " " "

Test of Iron Ore cement

Per cent passing No. 100 sieve, 95.8; No. 200 sieve, 82.6
Initial set — 45 min. Final set — 26 hr. — 22% water
Tensile strength neat test samples — 22% water

24 hours	average	000 (Cement did not have hard set)
48 hours	"	223 lb. per sq. in.
7 days	"	441 " " " "
28 days	"	641 " " " "

Tensile strength, one part cement to three of sand by weight —

(Ottawa sand)	7 days	average 132 lb. per sq. in.	— 10% water
	28 days	" 234 " " " "	
(Bank sand)	7 days	average 108 lb. per sq. in.	— 11% water
	28 days	" 174 " " " "	

Test of Portland cement with 0.1 hydrated lime added to 0.9 average alumina cement

Per cent of hydrated lime passing through No. 100 sieve, 95.2; No. 200 sieve, 88.2
Initial set — 10 min. Final set — 4 hrs. — 25% water
Tensile strength neat test samples — 25% water

24 hours	average	276 lb. per sq. in.
7 days	"	566 " " " "
28 days	"	717 " " " "

Tensile strength, one part cement to three of sand by weight —

(Ottawa sand)	7 days	average 148 lb. per sq. in.	— 9% water
	28 days	" 216 " " " "	
(Bank sand)	7 days	average 117 lb. per sq. in.	— 10% water
	28 days	" 182 " " " "	

Test of Portland cement with average alumina content mixed with 5% pulverized clay

Per cent of clay passing No. 100 sieve, 99; No. 200 sieve, 58
Initial set — 1 hr. 40 min. Final set — 4 hr. 40 min. — 22% water
Tensile strength neat test samples

24 hours	average	248 lb. per sq. in.
7 days	"	723 " " " "
28 days	"	762 " " " "

Tensile strength, one part of cement to three of sand by weight —

(Ottawa sand)	7 days	average 211 lb. per sq. in.	— 9% water
	28 days	" 255 " " " "	
(Bank sand)	7 days	average 169 lb. per sq. in.	— 10% water
	28 days	" 222 " " " "	

CHEMICAL ANALYSES OF CEMENT

	White Portland Cement	Average Alumina Cement	High Alumina Cement	Low Alumina Cement	Iron Ore Cement	Cement Made of Slag
Loss on Ignition	1.69%	0.96%	1.06%	1.04%	0.91%	2.82%
Silica (SiO_2)	24.58	22.08	21.46	23.40	24.28	20.42
Alumina (Al_2O_3)	8.22	7.21	8.50	5.61	0.94	8.04
Iron Oxide (Fe_2O_3)	0.29	2.57	2.44	2.37	9.08	3.04
Lime (CaO)	62.70	62.60	61.64	62.90	62.12	62.16
Magnesia (MgO)	1.11	2.74	2.58	2.51	0.43	1.63
Sulphuric Anhydride (SO_3)	1.32	1.56	1.75	1.53	1.75	1.73

Analysis of hydrated lime

Loss on ignition	1.32%
Silica and insoluble matter	18.73
Carbon dioxide	1.51
Alumina and iron oxide	0.68
Lime	45.88
Magnesia	31.62

EXAMINATION OF SAND AND BROKEN STONE

The sand, which was very fine, was clean and of good quality. As used, it contained 4.6% moisture. Dry, it averaged 97.18 lb. per cu. ft. The voids measured 34.2%. By weights the sand passed different meshes as follows:

No. 100	4.8%	No. 10	91.0%
50	24.0	8	93.4
30	52.0	6	96.1
20	73.4	¼ inch	100.0
16	86.4		

The stone was a broken trap, of very good quality, containing 50 per cent of voids by volume. It weighed 90.24 lb. per cu. ft. The fineness in passing sieves was represented by weights as follows:

⅛ inch	0.25%	½ inch	25.25%
3/16	0.50	¾	53.0
¼	1.75	1	80.75
⅜	9.75	1½	100.0

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